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Watermarking in Transform Domains (WTD)

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Abstract

In this paper two separate models of watermarking has been proposed based on wavelet and Z domain along with comparative study in terms of PSNR, MSE and IF. The cover image is passed through transformation based on 2 x 2 mask as sliding window manner in row major order to convert the spatial components of cover image into frequency coefficients. Four bits of authenticating image pixels are embedded into transform coefficients of each mask as watermark of the scheme to achieve the payload of one bpB (bit per Byte). Extraction is made in reverse manner. Results are computed and compared between two steganographic models in terms of Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), and Image Fidelity (IF) which show better performances in Z-domain with enhanced fidelity.

Keywords: Wavelet; Z-Domain; Frequency Domain; Mean Square Error (MSE); Peak Signal to Noise Ratio (PSNR); Image fidelity (IF), bpB(Bit per Byte).

1. Introduction

Steganography is a delicate tool to protect secret data. In cryptography the information is converted into unintelligent data, where as steganography hides the presence of secret data by keeping visible properties near to original. As criminal activities in cyber system growing rapidly, government of every country is eagerly waiting for new techniques of authentication. As a result steganography plays a very important role. The Steganography starts its journey with replacement of LSB, then slowly and gradually it developed a lot in both spatial and frequency domain. In the year 1997 a comparison is made between “Fourier Analysis and Wavelet Analysis [1] by James S. Walker in terms of steganographic techniques. In 2007 Guillaume Lavoue presents a non-blind watermarking scheme for subdivision surfaces [2]. Chin-Chen Chang in the same year proposed reversible hiding in DCT-based compressed images [3].

The main objective of this paper (WTD) is to emphasis on frequency domain watermarking techniques, especially Wavelet and Z-domain along with comparison of performances in terms of statistical analysis. Various parametric tests are performed and results obtained are compared based on Mean Square Error

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(MSE), Peak Signal to Noise Ratio (PSNR), and Image Fidelity (IF) analysis [4] to represent correlation among techniques.

The schemes have been described in section 2. Results and discussions are outlined in section 3. Conclusions are drawn in section 4 and references are given at end.

2. The WTD Scheme

This paper proposed two frequency domains based steganography/watermarking techniques, WTDW and WTDZ both of them converts the cover image into its frequency domain through Wavelet transformation and Z-domain transformation respectively followed by embedding the secret image as 1.0 bit per byte(bpB). The overall procedure of the schemes are described in section 2 out of which the WTDW has been described in section 2.1 and that of WTDZ in section 2.2.

2.1. WTD using Wavelet(WTDW)

In WTDW technique the cover image of size 512 x 512 is taken to authenticate it through watermark using authenticating image of dimension 180 x 180.The detailed procedure has been described in section 2.1.1 to 2.1.3.

2.1.1. Wavelet based Transformation

Transform equation is available in pair which is reversible and termed as forward and inverse transformation respectively [5]. In Wavelet based forward transformation the image converts from spatial domain to frequency domain using eq (1) and eq (2), and of inverse transformation the reverse procedure is followed (eq.(3)). Mathematically the image matrixes multiply with scaling function coefficients and wavelet function coefficients to generate the transformation matrix [6].

$$Y_{Low}[k] = \sum_n x[n].h[2k-n] \tag{1}$$

$$Y_{High}[k] = \sum_n x[n].g[2k-n] \tag{2}$$

$$x[n] = \sum_{k=-\infty}^{\infty}\left(Y_{High}[k].g[2k-n]\right) + \left(Y_{Low}[k].h[2k-n]\right) \tag{3}$$

where x[n] is original signal, h[x] is half band low pass filter, g[x] is half band high pass filter, $Y_{Low}[k]$ is output of high pass filter after sub sampling by 2, $Y_{High}[k]$ is output of low pass filter after sub sampling by 2. Cover images of 512 x 512 dimension are taken and Haar forward transform scaling function coefficients and wavelet function coefficients [6] $H_0 = ½$, $H_1 = ½$, $G_0 = ½$ $G_1 = -½$ are applied. The graphical representation of the results on forward DWT is shown in figure 1.

Low resolution sub-image $\psi(x, y)= \varphi(x)\varphi(y)$	*Horizontal Orientation sub-image* $\psi^H(x,y)=\varphi(x)\psi(y)$

Vertical Orientation sub-image	*Diagonal Orientation sub-image*
$\psi^V(x, y)= (x)\varphi(y)$	$\psi^D(x,y)=\psi (x)\psi(y)$

Fig. 1. Image decomposition in Wavelet transforms

Inverse transformation is just reverse of the forward transformation where column transformation done first followed by row transformation. But the coefficient values are different for column/row transformation matrices. The coefficient for reverse transformation are $H_0 = 1$, $H_1 = 1$, $G_0 = 1$, $G_1 = -1$ [6]. Reverse transform generate original image matrix as the technique is reversible.

2.1.2. Embedding

During first level forward transformation the cover image generates four quarters of frequency matrix as outputs. To embed secret information with minimum distortion vertical and diagonal coefficients [7] are used. A hash function is used to generate positions of embedding two bits per byte of coefficients matrix. Positions are selected using formula (B %P) and (B %(P +1)) where P varies from 0 to 4 and B equals to 2, which select position of embedding up to fourth position from LSB towards MSB randomly.

2.1.3. Authentication

To regenerate the secret image at receiving end, stego-image passes through forward Wavelet transformation and two bits per bytes from vertical and diagonal coefficients are extracted based on same hash function. This bit streams are compared with secret image for the purpose of authentication.

2.2. WTD using Z(WTDZ)

Proposed WTDZ model is based on the discrete two dimensional Z- transformation technique. The Z-domain transform is applied on sub-image block of size 2 x 2 in row major order on the cover image to generate frequency components of the corresponding spatial data[9]. Image authentication is done by hiding secret message/image into the real part of the frequency component of the cover image with a rate of 1.0 bit per byte. Transformations in Z-Domain is described in section 2.2.1. Embedding is described in section 2.2.2 that of authentication is fabricated in section 2.2.3.

2.2.1. Z-domain based Transformation

A special function in two dimensional space $g[n_1,n_2]$ where (n_1,n_2) is spatial coordinate can be represented in Z-Transformation as

$$F(Z_1,Z_2) = \sum_{n1=0}^{M-1} \sum_{n2=0}^{N-1} g[n_1,n_2] {z_1}^{-n1} {z_2}^{-n2} \tag{4}$$

where Z_1 and Z_2 are both complex number consisting of both real and imaginary part. Since z1 and z2 are complex numbers, let z_1=ejω$_1$π and z2=ejω2π, where ejω = cosω + jsinω. Substituting the values of z1 and z2 in equation (4), the equation becomes the discrete form of two dimensional Z -Transformation equation. Here region of convergence r1 and r2 both taken as 1 which leads to two dimensional Z-Transform equation as

$$F(e^{j\omega_1\pi}, e^{j\omega_2\pi}) = \sum_{n_1=0}^{M-1}\sum_{n_2=0}^{N-1} g[n_1,n_2]e^{j\omega_1\pi(-n_1)}.e^{j\omega_2\pi(-n_2)} \quad (5)$$

$$= \sum_{n_1=0}^{1}\sum_{n_2=0}^{1} g[n_1,n_2]e^{-j\pi(n_1\omega_1+n_2\omega_2)} \quad (6)$$

where ω_1 and ω_2 are two independent angular frequency variables $-\pi$ to π and 2×2 submatrix is considered for computations .

In special case where a 2 x 2 matrix has been taken as mask for transformation, equation 6 can be expressed as

$$F(\omega_1,\omega_2) = \sum_{n_1=0}^{1}\sum_{n_2=0}^{1} g[n_1,n_2]e^{-j\pi(n_1\omega_1+n_2\omega_2)} \quad (7)$$

The continuous Inverse Z-Transform of a function $F(z_1, z_2)$ is represented as

$$g[n_1,n_2] = \left(\frac{1}{2\pi j}\right)^2 \oiint F(z_1, z_2)z_1^{n_1-1}z_2^{n_2-1}dz_1dz_2 \quad (8)$$

where $g[n_1,n_2]$ be a function in spatial domain and $F(z_1,z_2)$ be the Z-Transformed of the function $g[n_1,n_2]$. Control integration is for irregular spaces in Z-domain.

Since z_1 and z_2 are complex numbers, Let $z_1=e^{j\omega 1\pi}$ and $z_2=e^{j\omega 2\pi}$, where $e^{j\omega\theta}= \cos \omega\theta + j\sin\omega\theta$. Substituting the values of z_1 and z_2 in equation (8), we have a discrete form of inverse Z Transform for two dimensions. Now $z_1=e^{j\omega 1\pi}$, differentiating this with respect to ω_1 we get $dz1/d\omega1 = e^{j\omega\omega 1\pi}j\pi$, therefore $dz_1=e^{j\omega 1\pi}j\pi\ d\omega_1$ and $z_2=e^{j\omega 2\pi}$, differentiating this with respect to ω_2 we get $dz2/d\omega2 = e^{j\omega\omega 2\pi}j\pi$, therefore $dz_2=e^{j\omega 2\pi}j\pi\ d\omega_2$. The equation (8) becomes

$$g[n_1,n_2]= \left(\frac{1}{2\pi j}\right)^2 \oiint F(e^{j\omega 1\pi}, e^{j\omega 2\pi})e^{j\omega 1\pi^{n1-1}}e^{j\omega 2\pi^{n2-1}}e^{j\omega 1\pi}j\pi\, d\omega 1\, e^{j\omega 2\pi}j\pi\, d\omega 2 \quad (9)$$

Assumed that contour integration is clockwise, so angular frequency ($z = re^{j\omega}$) ω will vary $-\pi$ to π. As a result both ω_1 and ω_2 will vary from 0 to π, equation (9) will converge to a definite integral as given in equation (10).

$$g[n_1,n_2] = \sum_{\omega_1=0}^{1}\sum_{\omega_2=0}^{1} F(\omega_1,\omega_2)e^{j\omega_1}e^{j\omega_2}d\omega_1 d\omega_2 \quad (10)$$

The equation (11) is the discrete form of two dimensional inverse Z -Transform.

$$g[n_1,n_2] = \frac{1}{4}\sum_{\omega_1=-1}^{1}\sum_{\omega_2=-1}^{1} F(\omega_1,\omega_2)\, e^{j\pi(n_1\omega_1+n_2\omega_2)} \tag{11}$$

2.2.2. Embedding

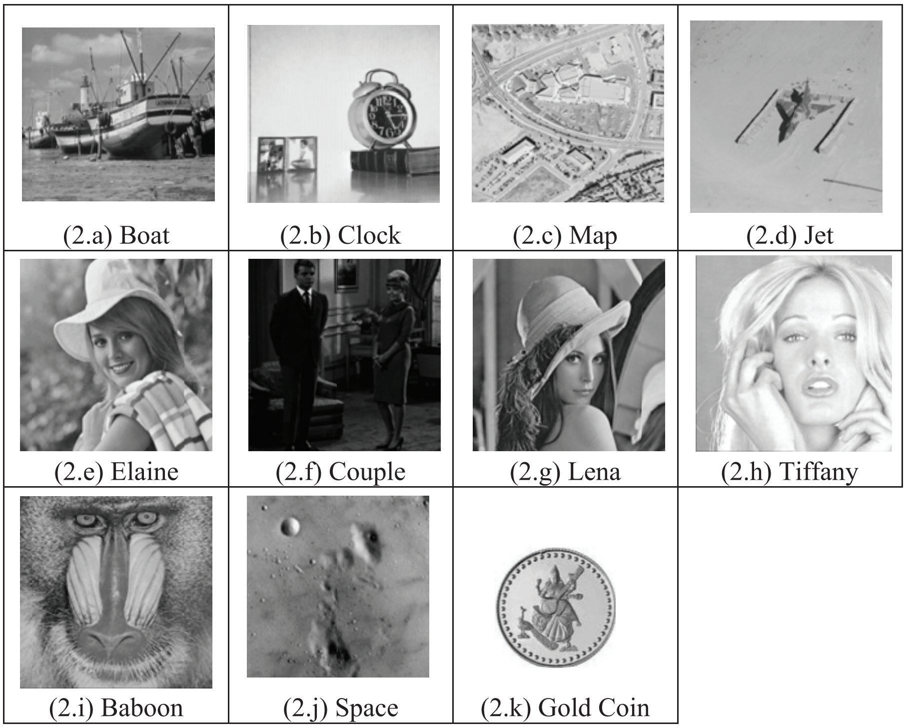
The cover image is transformed into its frequency components using Z-Transformation to generate frequency coefficients. A 2 x 2 mask in row major order is taken for the purpose. The embedding is done on second and third frequency coefficients in row major order. Two LSB bits in each of second and third components have been replaced by authenticating bits to obtain watermark at the rate of 1.0 bpB. Decoding is done in reverse order.

2.2.3. Authentication

To regenerate the secret image at receiving end, stego-image passes through forward Z-Transformation and two bits per bytes from second and third frequency coefficients are extracted from two LSB positions of each coefficient. This bit streams are compared with secret image for the purpose of authentication.

3. Results and Discussions

The proposed WTDW and WTDZ techniques are applied on ten PPM [8] images to formulate results. All cover images are 512 x 512 in dimension and secret image of dimension 180 x 182 are used as authenticating image. The images are given in fig 2.



(2.a) Boat (2.b) Clock (2.c) Map (2.d) Jet
(2.e) Elaine (2.f) Couple (2.g) Lena (2.h) Tiffany
(2.i) Baboon (2.j) Space (2.k) Gold Coin

Fig. 2. Cover images of dimension 512 x 512

Table 1, shows the MSE, PSNR, and IF for ten gray scale cover images (512 x 512) on embedding Gold Coin (180 x 182). Bits from authenticating image are embedded as payload of 1.0 bpB into the cover image. In case of WTDW positions are selected using a hash function whereas in case of WTDZ two LSB bits are replaced in second and third coefficients in row major order. The average MSE, PSNR and IF obtained in WTDW are 7.2086382, 39.5786216 and 0.999692 respectively (table 1). But in case of WTDZ the average MSE, PSNR and IF obtained are 2.4271044, 44.3188149 and 0.9998958 respectively (table 2). From these two implementations it is confirmed that in case of WTDZ the results produced is much better than WTDW.

Table 1. Parametric values on applying WTD based WTDW over 10 images embedding using Gold Coin

Cover Image 512 x 512	MSE	PSNR	IF
(2.a) Boat	6.823147	39.790956	0.999641
(2.b) Clock	8.766872	38.702357	0.999768
(2.c) Map	6.886765	39.750651	0.999798
(2.d) Jet	8.289124	38.945717	0.999735
(2.e) Elaine	6.700912	39.869464	0.999735
(2.f) Couple	7.121307	39.605206	0.999574
(2.g) Lena	7.248611	39.528255	0.999590
(2.h) Tiffany	6.496017	40.004332	0.999856
(2.i) Baboon	5.974525	40.367769	0.999679
(2.j) Space	7.779102	39.221509	0.999544
Average	***7.2086382***	***39.5786216***	***0.999692***

Table 2. Parametric values on applying WTD based WTDZ over 10 images embedding using Gold Coin

Cover Image 512 x 512	MSE	PSNR	IF
(2.a) Boat	2.150826	44.804752	0.999887
(2.b) Clock	3.298851	42.947177	0.999913
(2.c) Map	2.287804	44.536616	0.999933
(2.d) Jet	2.758835	43.723547	0.999912
(2.e) Elaine	2.227814	44.652015	0.999892
(2.f) Couple	2.492081	44.165183	0.999851
(2.g) Lena	2.357239	44.406768	0.999867
(2.h) Tiffany	2.345711	44.428059	0.999948
(2.i) Baboon	2.046616	45.020441	0.999890
(2.j) Space	2.305267	44.503591	0.999865
Average	***2.4271044***	***44.3188149***	***0.9998958***

A comparative study of proposed watermarking techniques using WTDW has been made with WTDZ in terms of peak signal to noise ratio. Comparison is done on average of randomly selected ten images shown in table 3. From the tables it is clear that the proposed data embedding/authentication technique using WTDZ obtained better performances. The graphical representation of the comparison of MSE and PSNR between WTDW and WTDZ are shown in figure 3 and figure 4 respectively.

Table 3. Comparison of average PSNR of ten benchmark images between WTDW and WTDZ

Schemes	WTDW	WTDZ
Average PSNR	39.5786216	44.3188149

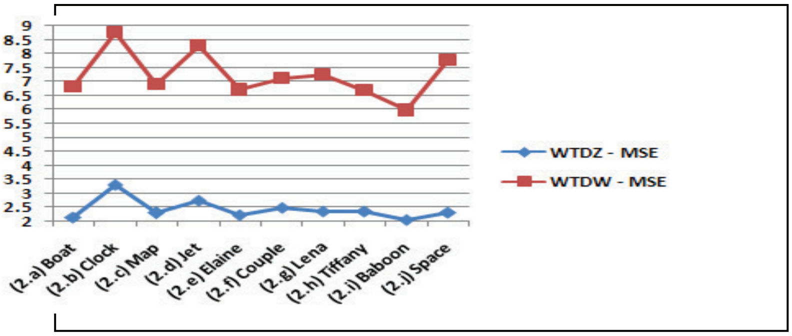


Fig. 3. Graphical representation of comparison between MSE of WTDW and WTDZ

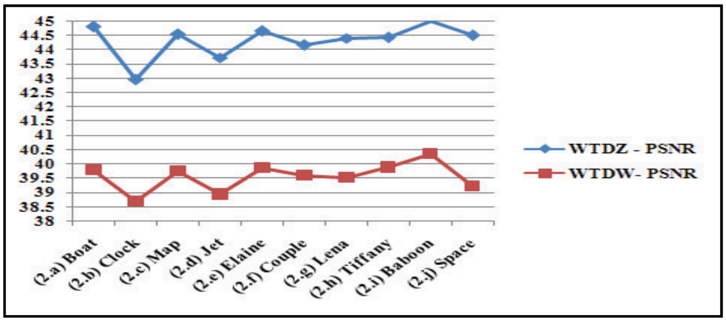


Fig. 4. Graphical representation of comparison between PSNR of WTDW and WTDZ

Few embedded images are shown in figure 5 to conform negligible changes on embedded images on applying WTDW and WTDZ techniques. The changes are not possible to detect through human eyes as they are very minute as shown statically in tables(1 and 2).

Embedded Baboon in WTDW	Embedded Baboon in WTDZ	Embedded Boat in WTDW	Embedded Boat in WTDZ

Embedded Elaine in WTDW	Embedded Elaine in WTDZ	embedded Lena in WTDW	embedded Lena in WTDZ

Fig. 5. Embedded Images with both WTDW and WTDZ technique

4. Conclusions

In this paper two separate frequency domain based techniques have been addressed to authenticate image/documents. On comparison between WTDW and WTDZ it conformed from present implementations that WTDZ obtained better MSE, PSNR and IF values. The achievement for presentation implementation in terms of payload is one bpB for both WTDW and WTDZ which is considerably high.

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